Synergies

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Disclaimer

This talk assumes that we all have read the Snowmass and P5 reports.

Given the goal of this workshop, I am presenting a very U.S.-centric view (apologies to all non-U.S. colleagues).

Open questions

In the context of three active neutrino flavors

- Is θ_{23} maximal and if not what is the octant?
- What is the mass hierarchy?
- Is there CP violation in the lepton sector?
- Is the three flavor framework complete?

In a world of infinite funding there is an obvious facility addressing all four questions with the best possible accuracy . . .

θ_{13} is known

$\sin^2 2\theta_{13} = 0.084 \pm 0.005$ Daya Bay, Neutrino 2014

θ_{13} is large, enables new approaches

- for the octant: any experiment
- for mass hierarchy: global fits, JUNO, PINGU, NOνA
- for CP violation: global fits, next generation superbeam experiments

θ_{13} is precisely determined, which is crucial for

- for the octant: any experiment
- for mass hierarchy: global fits
- for CP violation: global fits

Octant

The octant is hard to measure and even an optimal facility has limited reach. There are four principal ways to do this

- $\nu_\mu \to \nu_e \propto \sin^2\theta_{23} \sin^2 2\theta_{13}$, using θ_{13} from reactor – LBL + Daya Bay
- $\nu_\mu \to \nu_\mu$ compared to $\nu_\mu \to \nu_e$ – LBL
- interference effects between the Δm^2_{31} and Δm^2_{21} oscillations – JUNO
- matter effects in m $\nu_\mu \to \nu_\mu$ – PINGU

2-3σ from LBL experiments, unlikely that PINGU or JUNO would greatly exceed that – octant as a by-product?

CP violation

CP violation measurements can be done only in appearance experiments – disappearance experiments are sensitive only to $\cos\delta$ and the level of accuracy required to even measure $\cos\delta$ in disappearance is prohibitive – this is the exclusive domain of appearance measurements using man-made sources

In terms of an intermediate program this implies we are talking about T2K and NOνA and there is room for optimization, but essentially these are set programs. In combined fits, θ_{13} from Daya Bay plays a crucial role.

Beyond intermediate there is ELBNF, HyperK, . . . not part of this discussion

Mass hierarchy

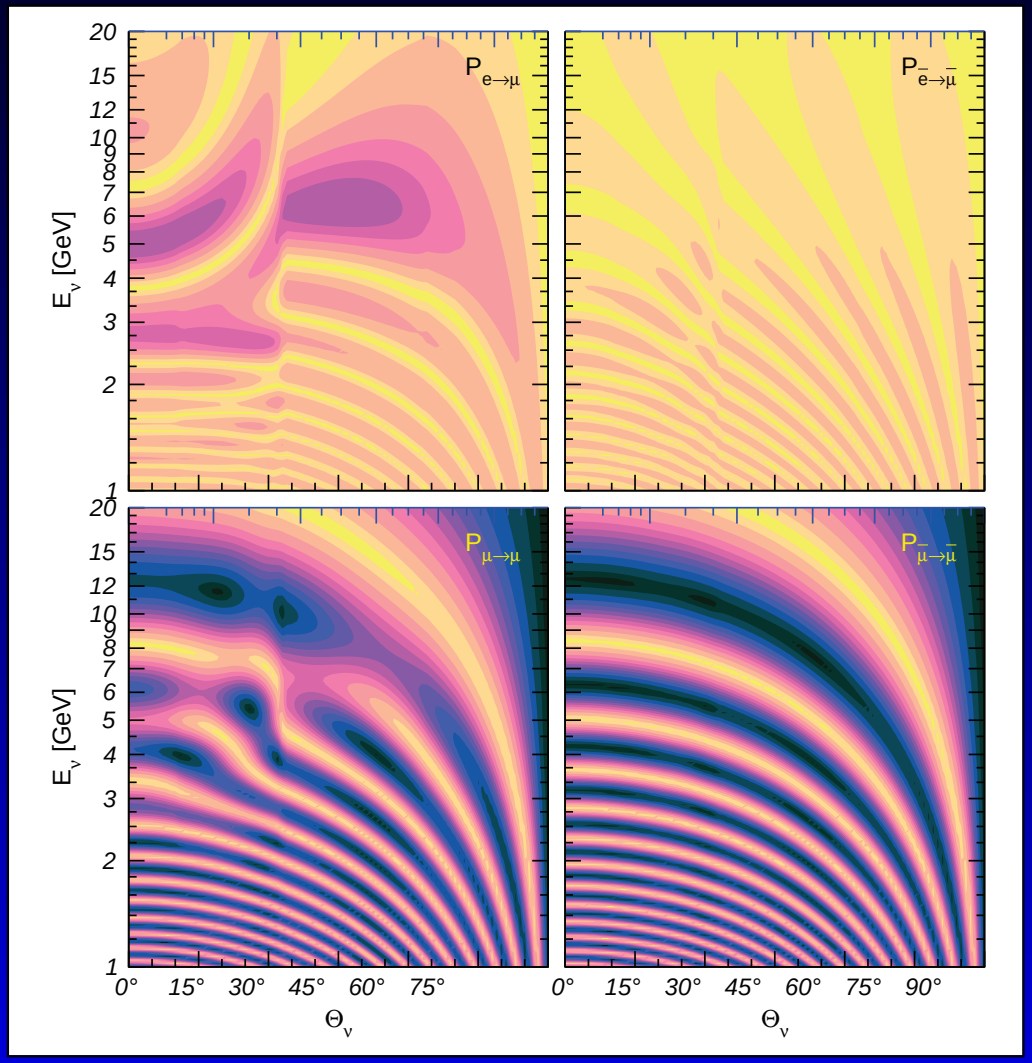
Knowing the mass hierarchy has direct impact in $0\nu\beta\beta$ searches and direct neutrino mass determinations based on β-decay

The mass hierarchy can be measured by either exploiting

- matter effects – LBL, atmospheric
- interference between Δm^2_{31} and Δm^2_{21} – JUNO

Measurements relying on the matter effect are highly correlated with the measurement of the CP phase, unless the magic baseline condition is fulfilled.

MH via atmospheric neutrinos

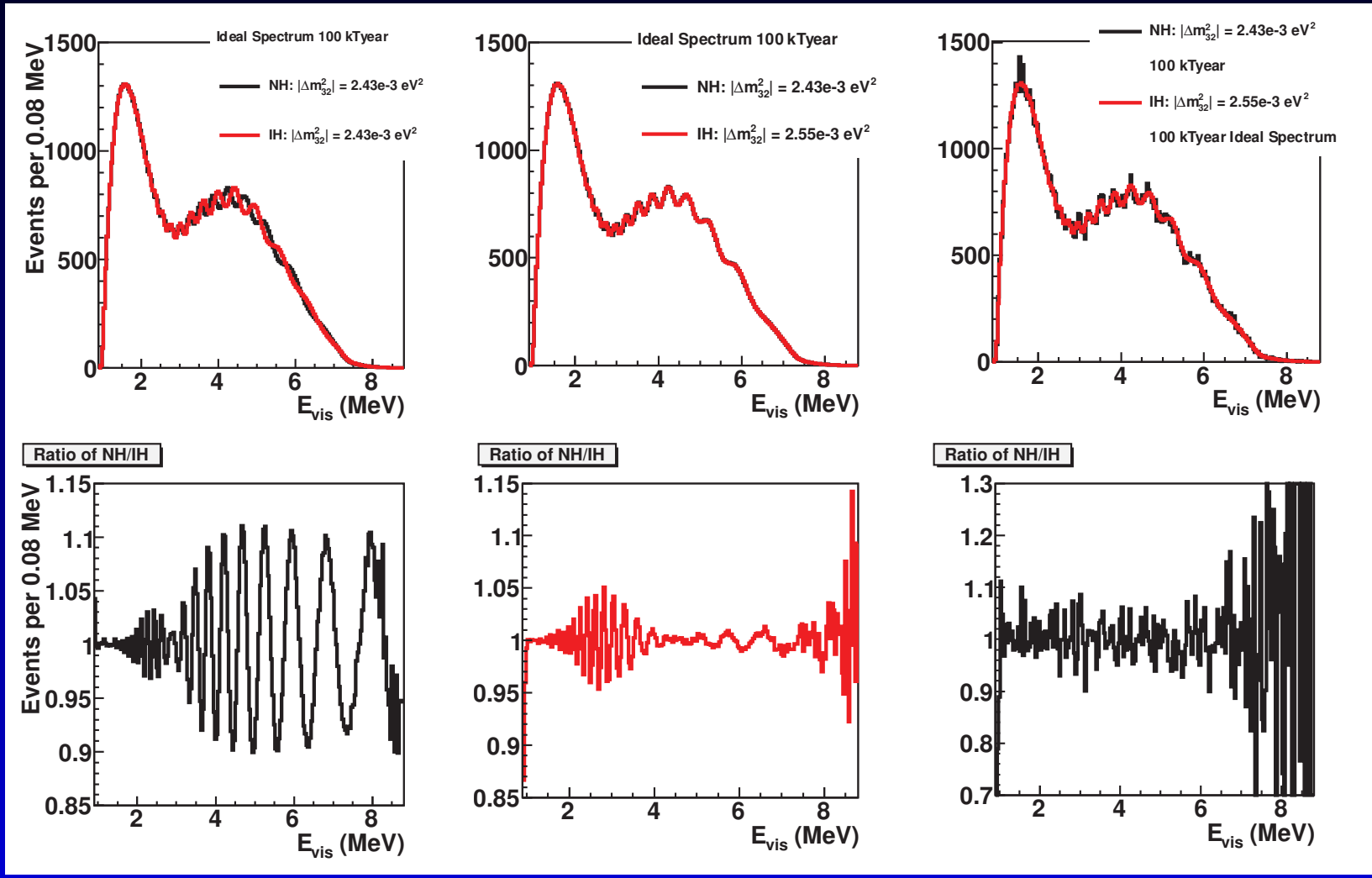


Akhmedov, Maltoni, Smirnov, 2006

This measurement relies on matter effects and their characteristic imprint in the energy and angular (proxy for baseline) distribution of events.

Very small event rate in the relevant $E - \cos\theta$ range

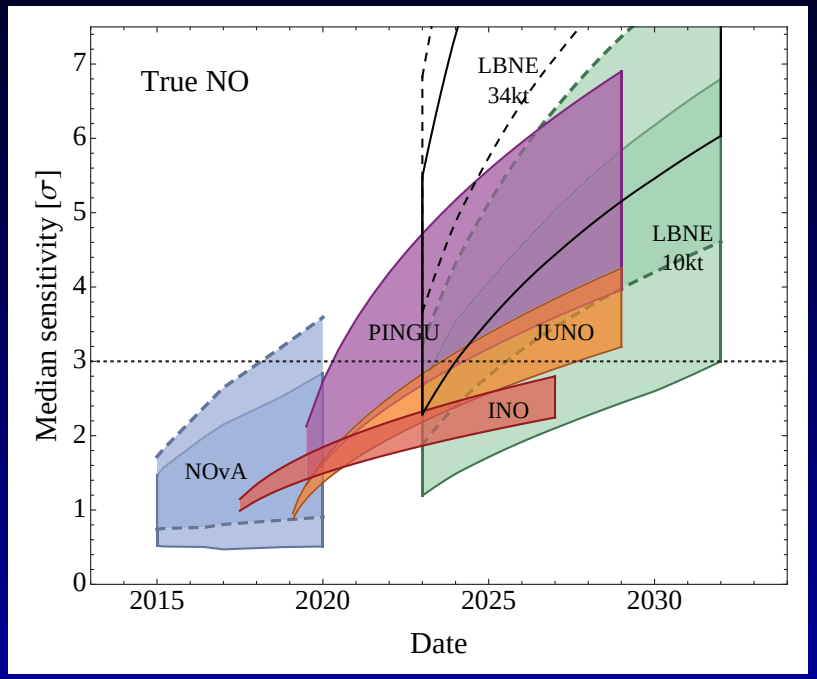
MH via interference

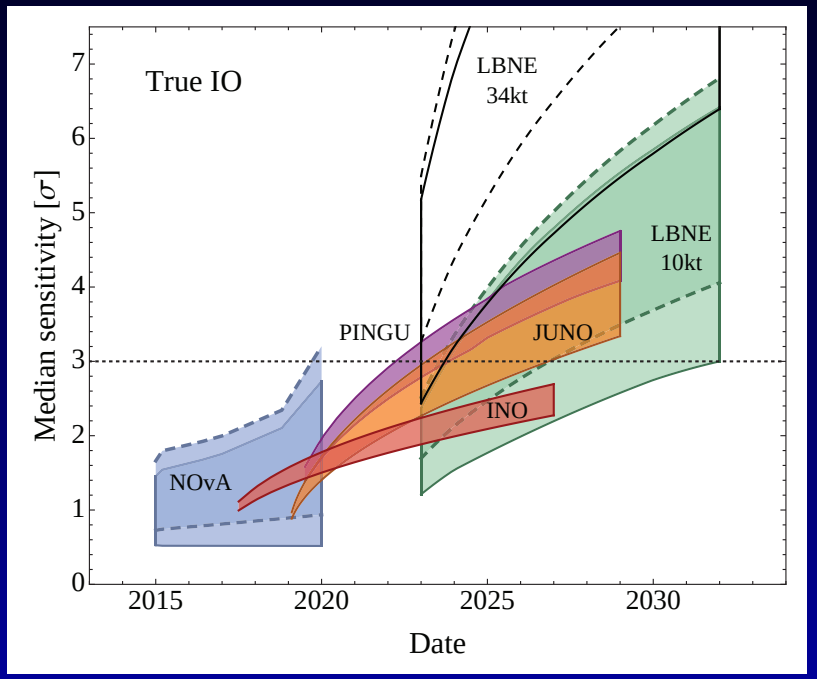


arXiv:1307.7419

Requisite energy resolution required

MH comparison



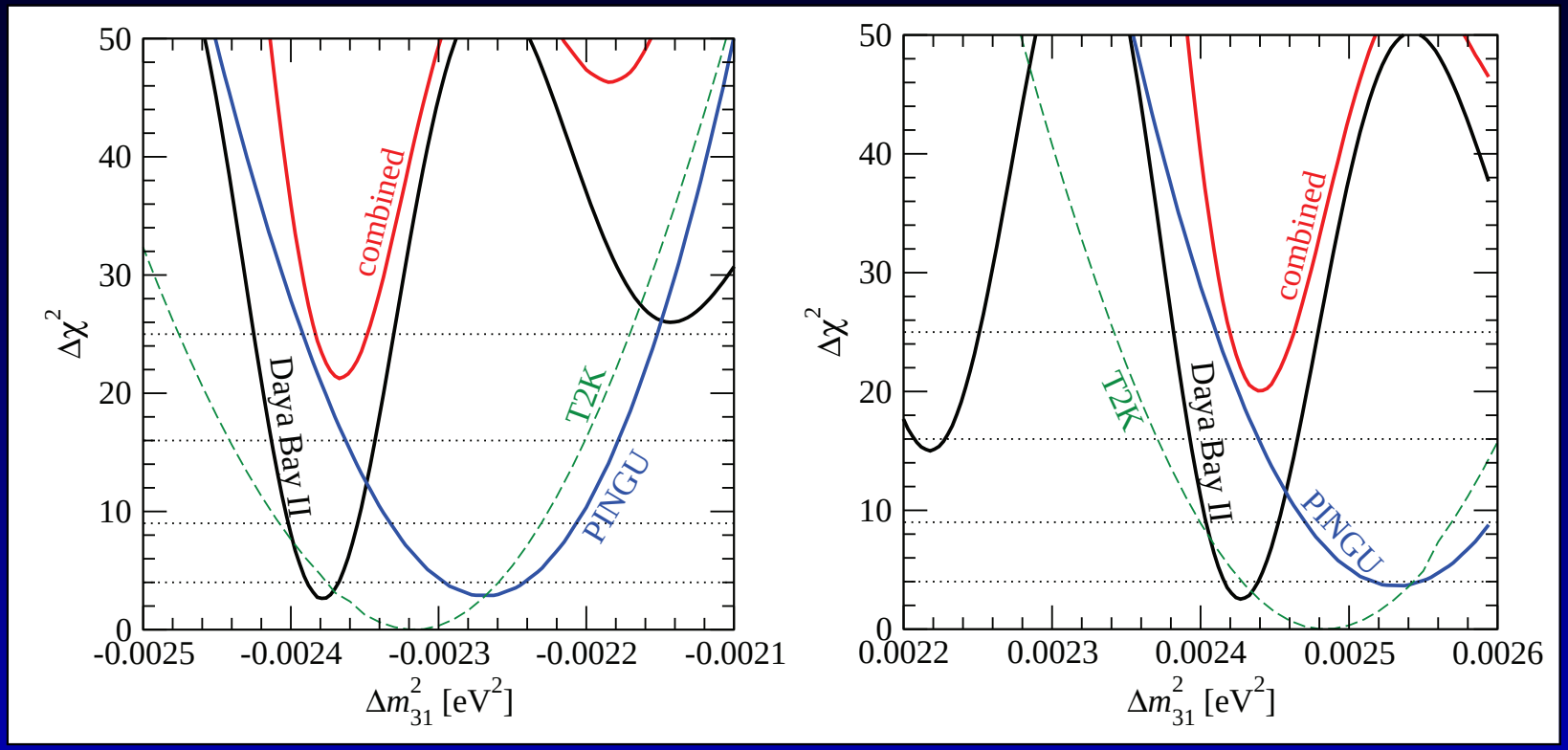


Blennow, Coloma, Huber, Schwetz, 2014

Bands due to:

- CP phase for NOνA and LBNE
- θ_{23} for INO and PINGU
- energy resolution for JUNO

MH synergy



Blennow, Schwetz, 2013

JUNO and PINGU combined would provide a $> 4\,\sigma$ MH determination, but so will ELBNF . . .

Summary

ELBNF will begin data taking in the middle of the next decade and will provide excellent sensitivity to many of the open questions in 3-flavor oscillation physics

In the interim, the combination of T2K, NOνA and Daya Bay can achieve some mass hierarchy sensitivity if the CP phase is favorable (supported by current global fits).

JUNO and PINGU offer the possibility to obtain a mass hierarchy measurement at a significance and on a time scale which is in between existing experiments and ELBNF.

Question

Given that we have some ability to measure the mass hierarchy with existing facilities (NOνA, T2K, Daya Bay) and will have a comprehensive capability with ELBNF a decade from now, is it an effective use of our scarce resources to build a new generation of experiments in the interim addressing this very same question?